Distributed Mobile Teams: Effects of Connectivity and Map Orientation on Teamwork

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ABSTRACT

Fielded first responders are currently being equipped with support tools to improve their performance and safety. Novel information technology provides opportunities for improvement of task efficiency and situation awareness, but people can get in trouble when data networks fail. In this paper, we examine the effect of glitches in the data network on team performance and look into the strategies people use to cope with these disruptions. Teams of three responders collaborated in a search and rescue task, supported by a map showing their positions and the locations of victims. Data communication required for this support was interrupted, verbal communication remained possible. Two variants were used for the map: a north-up version and a heading-up version that was aligned with the orientation of the responder. Negative effects and changing strategies were found for the condition with interruptions, no differences were found for the two map variants.

Keywords

Team collaboration, network connectivity, map orientation, virtual environments, decision support, first responders.

INTRODUCTION

In large-scale emergency situations or disasters, fielded first responders, such as firemen, policemen, and medics, have to collaborate with each other as a team, quickly and in an effective and efficient way (Van der Kleij et al., 2008). Consequently, they need to act in concert, and smooth and efficient communication is essential. Because first responders come from different organizations, collaboration is not always optimal due to differences in language, knowledge, culture, or priorities. Currently, coordination is carried out using walkie-talkies and first responders rely heavily on the incident commander to provide high-level information (Wagner et al., 2004). The situation is often highly dynamic and chaotic and first responders must adapt their response as the situation unfolds, translating into high levels of cognitive load and suboptimal collaboration between team members. Given the complexity of large-scale emergency situations, often much information must be processed when making decisions. Some of the information needs are geospatial, such as digitized maps of the disaster area. Other information needs are for real-time information based on reports from the incident commander, emergency services, and other parties involved in the emergency situation. This information together enables geographically dispersed teams of fielded first responders to get an accurate picture of what is happening, helping them to coordinate their collaborative efforts and fight the crisis effectively.

Johansson et al. (2007) found that teams using information systems combining real-time positioning of resources, fellow responders, and fire outbreaks, outperformed teams using paper maps when extinguishing a simulated forest fire in terms of saved area. Moreover, communication volume was reduced between the geographically separated command module and ground chiefs in support teams. These teams exchanged significantly fewer messages via e-mail than teams using paper maps. Because these teams had an accurate picture of what was going on in the area of operations, there was less need for communication concerning one's own and others' position, and the locations of the fires. Moreover, Van der Kleij, et al. (2008) found that presenting complete and reliable geospatial information, and real-time situation updates, improves performance, satisfaction, and information exchange of geographically dispersed teams of fielded first responders. Participants performed a search and rescue team task and were equipped with a digitized map and real-time situation updates on the location of other participants in a simulated disaster area. Interestingly, these benefits were accomplished at the costs of higher mental workload when compared to teams with no network connection whatsoever. Apparently, participants needed to accelerate their cognitive functioning to process the real-time geospatial information and to coordinate their joint effort. Thus, both the need for information exchange and communication were increased, thereby increasing their effort expenditure.

Mobile handheld computers may be employed to address the information needs of first responders and support situation assessment. By augmenting fielded first responders with wireless communication technology, these devices can become electronic communicators, capable of delivering real-time situation updates, providing information on the location of other responders, and providing information on the victims. For example, through the use of global positioning satellite technology, automatic reporting of responder location can be achieved, reducing the communications workload on the responder. Emergency services see a lot of potential in such devices to make better decisions, faster, with a greater attention to detail, and with a near optimal utilization of teams and resources (Van der Kleij & Schraagen, 2006; Wagner et al., 2004).

This paper describes the results of an experiment addressing two research questions. The first is the effect of failing data connections on communication and collaboration for self-organizing crisis-management teams performing a search and rescue task. To answer this question, teams either collaborated in an environment with perfect connectivity or in an environment with occasional network failure. The second question relates to the effect of using heading-up maps in tasks that require coordination. Coordination is defined as a process by which team resources, activities, and responses are organized to ensure that tasks are integrated, synchronized, and completed within established temporal constraints (Cannon-Bowers et al., 1995). It is expected that heading-up maps, although effective for single-person tasks, may harm coordination because team members no longer look at the same picture and, consequently, it becomes more difficult to engage in synchronized actions. In the next section, the research questions are addressed in more detail. Next, the design and results of the experiment are presented. This paper will end with a discussion of the findings.

RESEARCH QUESTIONS

Connectivity

New mobile data communication technologies make it possible for emergency services to have immediate access any place and any time to information needed for the execution of their tasks. For example, firemen situated in a crisis area can use a Personal Digital Assistant (PDA) to gather information about the situation and use this information instantly for the execution of their task. When information is available to all team members, the need for explicit communication and coordination diminishes. The information informs them on their colleagues' activities and they can often adjust their own activities without explicitly discussing details. Teams are then said to be working self-organized. Self-organization assumes good network connectivity to provide everybody with reliable and up-to-date information. In practice however, disconnection of varying lengths are rather common. In this study, we make a distinction between a strongly connected network that provides reliable data communication, and a weakly connected network that suffers from interruptions, and examine the effect on coordination and team performance.

North-up and heading-up displays

Research has shown that for navigational purposes (going from A to B as quickly as possible) heading-up displays are generally better than north-up displays. A drawback of heading-up displays is that due to the continuous rotation of the map development of situational awareness is hampered. Therefore, it depends on the characteristics of the tasks at hand which representation should be chosen.

When people work in teams and have to communicate with each other while making references to the map, heading-up displays may make communication more complex. People are looking at differently oriented maps, which can trouble effective communication. Therefore, for tasks with a strong focus on coordination, north-up displays may be a better choice. In this experiment, we will examine this effect both in a qualitative and quantitative manner.

METHOD

Participants

Forty-five participants participated in the experiment as paid volunteers. There were 24 male and 21 female participants. The average age of the participants was 22. Their age ranged from 18 to 27 years (M = 21.87, SD = 2.46). All participants were university students. Although it would be preferable to use real first responders in this type of study, we expect that findings can be mapped to real-world situations because of the generic nature of the task. The task was performed by 15 teams: 10 mixed gender teams (of which 5 teams consisted of 2 males and 1 female), 2 female teams and 3 male teams. The students were selected from the database of the Human Factors lab of the Netherlands Organization for Applied Scientific Research (TNO). All participants had sufficient computer experience to be able to perform the task.

Task

The teams of participants had the assignment to rescue victims that were distributed in a synthetic environment (see also Van der Kleij et al., 2008), that was generated with Unreal Tournament 2004. Unreal Tournament provides a dynamic and to some extend realistic multi user task environment (see Figure 1). Victims either had to be saved by one, two or three participants. In this manner, team members were obliged to collaborate. To stimulate collaboration we rewarded teams for working together: participants that had to be saved by one participant resulted in 1 point, two participants in 5 points and three participants in 10 points. These numbers were chosen such that collaboration is required to get good results and that flexibility in individual and team effort is necessary to obtain real high sores. Victims could be saved in by walking up to them, after which they disappeared both from the virtual world and the map.

Figure 1: Two scenes from the synthetic world generated by Unreal Tournament 2004.

A map of the virtual world was presented on a support screen that showed buildings (orange), a church (red), streets (gray) and parks, grass and trees (green) (shown in Figure 2). The colors of the map were taken from colors of maps on www.routenet.nl to have a familiar look and feel. Victims were indicated on the map by a black circle, a clock showing the time left to rescue a victim and a number indicating how many participants were needed to rescue it. The participants were shown as a red, blue or green circle.

Time pressure was exercised by the limited amount of time (two minutes) victims could be rescued and the number of victims present at the same time. Complexity was set by the number of victims present and the varying number of participants needed to rescue them. Dilemmas arose in choosing which victim to help at what time and by which participants. Location of the victims and participants in the environment, the number of participants needed and the time left for rescuing the victim had to be considered. One trial lasted for 12 minutes during which new victims appeared in the environment on different locations. The responders had to reach a victim within two minutes, or the victim would disappear from the support tool and the virtual world.

When the participant walked in the synthetic world, the screen showing the support map turned black. This was necessary to prevent the participants from navigating through the world solely by looking at the map. In real life, it is not possible to walk around while just looking at the map (with the exception of head-up tools), but due to the absence of pavements, car's and other obstacles it is possible in our synthetic world. When the participants stopped moving, the map was available immediately.

Figure 2: Example of the map provided as support, indicating the location of the responders (red, blue and green), and victims (numbered black circles).

The team was provided with visual feedback on the team score, the time that a particular victim could be rescued, the number of team members needed to rescue the victim, and whether a network connection was available. Audio feedback was provided when the connectivity failed or was regained, and when new victims were available. During a period of non-connectivity (lasting two minutes) the information on the map was not updated except for the participants own position which is provided by GPS for which no communication is required. At that time, of course, the other participants with a network connection no longer received updates of the position of the disconnected participant.

Research Design

The experimental design was within subjects. There were two independent variables, orientation of the map (north-up and heading-up) and connectivity (strongly connected or weakly connected). To exclude learning and order effects the order of the presented conditions was counterbalanced.

Dependent variables

Team performance

To objectively evaluate the team's performance, we calculated the overall team score by summing the points (1, 5 or 10, depending on the number of participants required to rescue a victim) gathered during the trial.

Participant ratings

Questionnaires on process and outcome satisfaction, information exchange, coordination, and a rating scale on mental effort were administered at the end of each experimental trial. The questionnaire items were measured on 7-point Likert scales in which a score of 1 corresponds to the most negative option and a score of 7 corresponds to the most positive option. Furthermore, an open-ended questionnaire was conducted at the end of the experiment to subjectively asses the support conditions. The questionnaires, the rating scale, and the interview are discussed in more detail below.

Process satisfaction — the contentment with the interaction while making decisions (Thompson et al., 2003) — was assessed with an adapted version of the questionnaires used by Green et al. (1980) and Dennis (1996). It contains the following two items: 'I am satisfied with quality of the interaction within the team' and 'I am satisfied with choices we made as a team' (2 items, Cronbach's $\alpha = .84$).

Outcome satisfaction includes the approval of the final team decision (Thompson et al., 2003). This questionnaire was adapted from (Green et al., 1980) and includes the following five items: 'I am satisfied with the final result we produced as a team', 'I am attached to the final results of our team', 'As a team we produced the best result conceivable', 'I am personal responsible for the final result our team produced' and 'My personal share is recognizable in the final result of our team' (5 items, Cronbach's $\alpha = .79$).

The sharing of members' information, expertise and knowledge is important in groups (Stasser et al., 1985). It was found that the effectiveness of groups fluctuates as a function of what information is shared and the degree that information is shared (Stasser et al., 1989) Information exchange was assessed with a questionnaire to assess the perceptions of the participants concerning the completeness, speed, and amount of information given and received in discussions while performing the task. The Information Exchange Scale includes the following four items: 'We had enough opportunity to exchange information', 'During the task accomplishment I shared a lot of information with my team members', 'Information could be exchanged without unnecessary delay', and 'When things were unclear during the task we asked each other for explanation' (4 items, Cronbach's $\alpha = .66$).

Coordination was measured to reflect the degree to which members coordinated their work efforts. The questionnaire includes the following three items: 'when needed we coordinated our joint efforts', 'I'm satisfied about the way we coordinated in the team', and 'It was always clear to me who coordinated the combined efforts' (3 items, Cronbach's $\alpha = .64$).

O'Donnell (1986) defines mental effort as the ratio between the task demands and the capacity of the operator working on the task. Mental workload is high when the difference between task demands and capacity is small. To evaluate mental effort the Dutch Rating Scale Mental Effort (RSME) was administered once per test session directly after completion of the task The RSME, originally developed by Zijlstra (Zijlstra, 1993), is a one-dimensional scale with ratings between 0 and 150. The scale has nine descriptive indicators along its axis (e.g., 12 corresponds to *not effortful*, 58 to *rather effortful*, and 113 to *extremely effortful*). It is designed to minimize individual differences. We selected the RSME because it is simple to administer, is not intrusive, and at the same time it provides a good indication of the total mental workload (Veltman and Gaillard, 1996).

At the end of the experiment, the participants were given an open-ended questionnaire to assess participants' subjective evaluation of the four different support conditions. With regard to overall subjective evaluation, participants were asked to specify how they experienced being connected through an error prone link and how they experienced rotating maps as compared to north up maps. Moreover, participants were asked to describe their strategies and how they were helped or hindered by the technologies at their disposal.

Procedure

Participants were assigned to a team of three. The participants had to fill out a general questionnaire containing questions about computer and game experience and demographic information including age, gender. The participants had previously participated in an individual experiment using Unreal Tournament and where thus acquainted with the environment. Before starting the experiment, participants conducted some practice trials to get used to the interaction and the map. This way all participants started with an approximate similar level of familiarization with Unreal Tournament and the controls. Participants were given 4 trials of 11 minutes each. In each trial the participants had to conduct the search and rescue task with a different combination of map orientation and connectivity. To prevent learning effects, the locations of the victims and the moment they were added varied. The effect of an increase in skills was eliminated by varying the order of the four conditions. After each trial participants were asked to fill out a questionnaire to assess their process satisfaction, solution satisfaction, mental effort, time pressure, information exchange and team coordination. The experiment took approximately 2 hours to complete.

Material

The participants navigated through the game using a game controller, and could turn and move forward, backward and sideways. The team members were situated in separate rooms next to each other and were seated at a table behind a 19 inch screen displaying the virtual world and a 17 inch screen showing the support map. During the experiment, participants wore headsets to communicate with each other. The setting of the experiment is shown in Figure 3.

Figure 3: Setting of the experiment. At the right screen the virtual world is presented, at the left screen the map.

A video camera was set up in a corner of each room in order to register collaboration, rescue strategies, team processes and performance. The registration was recorded and could be seen and heard in the experimenter's room.

RESULTS

Two-way within repeated-measures ANOVA was used to analyze the data. In all cases, an alpha level of .05 was used to determine statistical significance. Analyses were performed at the team level to account for statistical interdependence. Table 1 summarizes the means and standard deviations for the dependent variables across conditions.

Table 1: Cell means (M) and standard deviations (SD) of the dependent variables by support condition.

	Support condition			
Dependent variable	Heading up, weakly connected	Heading up, strongly connected	North up, weakly connected	North up, strongly connected
Team performance[a]	63.88 (10.22)	74.94 (11.67)	66.00 (9.70)	72.69 (8.58)
Process satisfaction[b]	5.32 (1.08)	5.99 (.68)	5.32 (.84)	5.62 (.93)
Outcome satisfaction[b]	4.99 (.98)	5.68 (.78)	5.15 (.75)	5.48 (.74)
Coordination[b]	5.29 (.87)	5.76 (.56)	5.48 (.73)	5.61 (.58)
Information exchange[b]	5.67 (.71)	6.11 (.40)	5.70 (.49)	5.88 (.50)
Mental effort[c]	50.89 (10.95)	52.68 (15.67)	52.71 (18.01)	50.23 (17.85)

Note. Values enclosed in parentheses represent standard deviations. [a]The values represent mean team scores on the task.[b] The values represent mean scores on seven-point Likert scales. [c]The values represent mean scores on a one-dimensional scale with ratings between 0 and 150. The scale has nine descriptive indicators along its axis (e.g., 12 corresponds to *not effortful*, 58 to *rather effortful*, and 113 to *extremely effortful*).

Demographic Characteristics and Experience with Computer Games

A baseline questionnaire was included at the beginning of the experiment that assessed basic demographic information, including age and gender, and participants' experience with working in teams, playing computer games, ego-shooter games, and Unreal Tournament. Since no differences were found between teams, meaning that the random allocation of participants to teams was successful, it is not discussed further.

Team Performance

No differences were found for orientation of the map, north-up or heading-up, F (1, 14) = .11, p = .74, η_p^2 = .00. This was rather unexpected, because we hypothesized that maps with a fixed orientation (i.e. north up) would help coordination in teams and consequently would lead to higher team scores. As expected, there was a significant main effect of connectivity on performance, F (1, 14) = 13.41, p = .003, η_p^2 = .48. Teams in the strongly connected condition performed better than teams in the weakly connected condition. No interaction was present between map orientation and connectivity, F (1, 14) = 2.04, p = .18, η_p^2 = .11. Post-hoc analysis revealed that the heading up, strongly connected condition different significantly from both the heading up, weakly connected condition (p = .007) and the north up, weakly connected condition (p = . 023), but not from the north up, strongly connected condition (p = .74).

Participant Ratings

Process satisfaction

No main effect for process satisfaction was found for orientation of the map, north-up or heading-up F (1, 14) = 1.77, p = .21, η_p^2 = .11. There was a significant main effect of connectivity, with two states, either connected or disconnected, F (1, 14) = 9.89, p = .007, η_p^2 = .41. Process satisfaction in the connected conditions was significantly higher than in both disconnected conditions. No significant interactions were found F (1, 14) = .67, p = .43, η_p^2 = .05.

Outcome satisfaction

No differences were found between conditions differing in map orientation on outcome satisfaction, F (1, 14) = 0.12, p = .91, η_p^2 = .001. There was a significant main effect of connectivity on outcome satisfaction, F (1, 14) = 8.34, p = .012, η_p^2 = .77. Teams that performed in connected conditions experience more satisfaction regarding the outcomes of their work. No significant interactions were found between map orientation and connectivity, F (1, 14) = .99, p = .34, η_p^2 = .07.

Information exchange

Again, no main effect was found for orientation of the map F (1, 14) = 1.83, p = .20, η_p^2 = .24. As expected, we did found a significant main effect for connectively on information exchange, F (1, 14) = 16.77, p = .001, η_p^2 = .97. Teams in the connected conditions reported to have better quality information exchange than teams in the conditions connected to each other over an error prone link. No significant interactions were found between map orientation and connectivity, F (1, 14) = 1.45, p = .25, η_p^2 = .09.

Coordination

We expected that the north-up map orientation would aid team members in their coordinated effort. To our surprise, however, no main effect for coordination was found for direction of the map, F (1, 14) = 0.23, p = .88, η_p^2 = .002. There was a significant main effect of connectivity on team coordination, F (1, 14) = 6.11, p = .027, η_p^2 = .63. Teams in the connected conditions coordinated significantly better than teams in both disconnected conditions. No significant interactions were found between map orientation and connectivity, F (1, 14) = .93, p = .35, η_p^2 = .18.

Mental effort

No main effect for mental effort was found for direction of the map, north-up and heading-up F (1, 14) = 0.21, p = .88, η_p^2 = .001. Further, no effect was found of connectivity, F (1, 14) = 0.25, p = .88, η_p^2 = .002. No significant interactions were found as well, F (1, 14) = .92, p = .35, η_p^2 = .06.

Subjective assessment of support conditions and strategies

As we expected participants, except for three, preferred the north-up map orientation over the rotating map. It helped them to better orientate and coordinate team efforts. Without a fixed map orientation, it became more difficult to aid other team members and discuss the locations of victims in the synthetic world. Moreover, there was a higher risk for communication mixed-ups to occur when working together with different map orientations. Because for what is "up" for on participant may well be "down" for another. One participants was of opinion that for the heading up map orientation to work in teams, it was necessary to make clear appointments as to which side of the map is referred to as up, and which side is referred to as down.

DISCUSSION AND CONCLUSIONS

Stable and reliable communication is very important for self-organizing virtual mobile teams. This study shows that process and outcome satisfaction are effected negatively by disruptions in data communication, and that also the quality of the information exchange between team members is lowered. Virtual mobile teams working under critical conditions can only work optimally if they have the disposition of strongly connected networks they can trust (cf. Van der Kleij et al., 2008).

Whether the support map was oriented north-up or heading-up did not yield different results for the selected measures of merit. We expected more coordination and communication for the heading-up condition, which was not reflected by the findings in the questionnaires. No significant effects where found for process or outcome satisfaction, information exchange or coordination. However, when the question was posed which of the two visualizations was preferred, 42 out of the 45 participants opted for the north-up display.

A first quantitative analysis of the team performance show similar results. Teams in the strongly networked conditions get significantly higher scores than teams suffering from interruptions in data communication. No difference in team performance was found for teams working with north-up versus teams working with heading-up maps.

It is remarkable that 42 out of 45 participants preferred the north-up display in this task, yet no effect was found on any of the performance measures. We will have to take a closer look at the logged data to explain this discrepancy. A possible explanation is that the participants compensated by increasing their verbal communication. Analysis of the verbal communication will be done to see whether the participants were using more or longer utterances in the heading-up condition. The teams also used different strategies. In the heading-up condition, reference points on the map were more often used for coordination, such as street names and notable buildings and squares. Although the participants said this was more demanding, apparently the map provided sufficient landmarks to support this type of coordination. Another explanation may be found in the higher navigation speed due to the rotating maps. Although coordination suffered from the lack of having identical maps, this may be counterbalanced by a decrease in walking time of the individual participants required to reach the victims.

In the weakly connected condition, people without an up-to-date information picture often teamed up with a fellow responder who did have a working connection. These two-person teams focused on victims that needed two persons to be rescued, the third responder focused on the other victims or participated when three responders were required. Apparently adopting new strategies did help with dealing with rotating maps to keep up performance, this was not the case when connectivity was disturbed.

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